Thermal Fracturing of Pack Ice

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LONG-TERM GOAL

The long-term goal of this study to identify and quantify the relationships between meteorological conditions, the thermal fracturing of pack ice, and the resulting under-ice noise variations.

OBJECTIVE

The objective of this program was to analyze SHEBA under-ice noise, meteorological, and stress data in order to improve a model that predicts thermal cracking rates.

APPROACH

The first step was to collect, process, and examine the data from SHEBA. The meteorological data include wind speed, air temperature, and longwave and shortwave radiation. Ice core data were used to calculate an average profile of ice salinity and porosity. Snow cover variations were combined into bins to produce a time history of the fractional coverage of snow as a function of time. Ice stress data from the Baltimore site were used to assess stress variations at the upper thicknesses and lower thicknesses of the ice. These data were used to drive the thermal stress model.

The flaw structure of the ice was adjusted in the model so at to match the observed stresses with that predicted by the model (there is no means of measuring this flaw structure). Hundreds of test simulations were performed with varying flaw structure for the top, middle, and bottom third of the ice, and one simulation was identified that was able to closely reproduce the observed stresses.

Finally, the thermal model was used to predict fracturing rates, which were fed into a seismo-acoustic propagation model. This propagation model also depends on the ice characteristics, which were found to be different during SHEBA than during previous experiments like CEAREX. Thus, a whole new set of relative noise level curves at 500 Hz were calculated and produced.

RESULTS

It was noticed that there were some peculiarities in the hydrophone data from SHEBA. There are different driving forces for the different frequency regimes. Thermal fracturing is the principal source for noise between 500 and 1000 Hz, while lower frequencies (50 Hz) are more closely related to ice motion. For certain periods, all frequencies (50-2000 Hz) were correlated too highly compared to previous experience. The following numbers show the correlations between pressures (in μPa) for various third-octave bands for SHEBA and for CEAREX.

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As can be seen, the CEAREX correlations are considerably smaller than those measured during SHEBA. Obviously, atmospheric and ice pack conditions could have been different enough between CEAREX and SHEBA to have caused the different correlations. An examination of the data from the two times does not support this possibility.

Under-Ice Frequency (Hz)	Under-Ice Frequency (Hz)	Linear Correlation Coefficient, SHEBA, Day 308-357, 1997	Linear Correlation Coefficient, CEAREX, Fall 1989
50	100	0.96	0.79
100	200	0.99	0.76
200	400	0.98	--
400	500	0.99	--
500	1000	0.98	0.43
50	500	0.89	0.59
50	1000	0.88	0.53
200	500	--	0.69

We have noted in earlier studies that lower frequency under-ice noise at times can have thermally-induced signatures. This is not a common situation, but it does open the possibility that all the SHEBA under-ice noise is being dominated by thermally-induced fracturing. If this were true, it would explain the high correlations. But for the most part, lower frequency under-ice noise is related to motion-induced phenomena. As a result, the lower frequencies are typically correlated to ice speed on the order of 0.6 to 0.7. However, with the SHEBA ice speed and noise data, there is no visual correlation. And the linear correlation coefficients between the ice speed of the SHEBA camp and 50 and 2000 Hz are only 0.15 and 0.17, respectively. Thus, it would seem that the variations of the under-ice noise, across the spectrum of frequencies up to 2000 Hz, are not a result of motion-induced processes.

These results draw our attention to the possibilities that a) thermally-induced fracturing in the pack ice during SHEBA occurred at such a wide variety of scales that the resulting under-ice noise dominates even at lower frequencies or b) there was a technical problem in the collection of the under-ice noise data. A means of further investigating this problem would be through utilizing the thermomechanics model for the ice pack that has been developed over the last 5 years. To use the model, we need ice pack salinity and porosity characteristics in the vertical as well as stress gauge data at several locations in the vertical. Moreover, temporal variations of the spatial distribution of snow cover are required.

The test simulations indicated that the top third of the ice was heavily flawed (cracks covering 80% of the top third of the ice), the middle third of the ice was less flawed (on 45% fractured), and the bottom third of the ice had flaws covering only 30% of the ice. Figure 1 shows the results of this simulation. In this way, the surface thermal stress was reduced fairly significantly (except for periods of compression). In addition, the model-predicted stress in the bottom third of the ice had little variability.

The SHEBA conditions are seen to be similar to those of CEAREX in terms of the estimated flaw structure of the pack ice. In CEAREX, we had estimated that the top third of the ice was 70% flawed, the middle third was 90% flawed, and the bottom third was 30% flawed. Thus, in the case of SHEBA, the interior of the floe is estimated to be substantially less flawed than the ice in CEAREX.

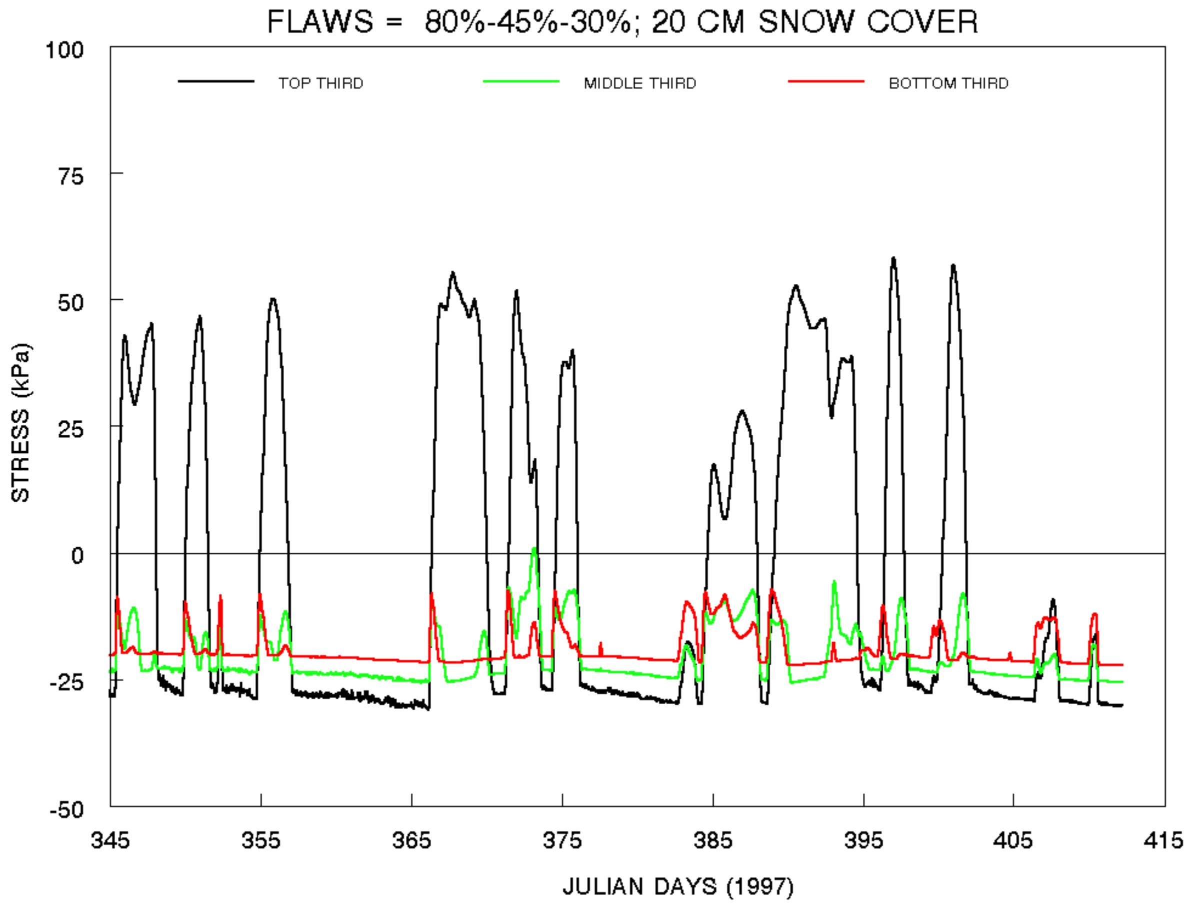

Fig. 1. Model-predicted stresses for the SHEBA forcing.

Since the SHEBA ice core salinities and porosities were so much different than expected, we can expect that the elastic propagation of energy from thermally-induced fracturing to be different than that seen during CEAREX. As in CEAREX, we estimated the Young's elastic moduli within the ice by taking the calculated effective elastic moduli and adding 3 GPa. The estimated Young's moduli for day 290 for different snow covers are shown in Fig. 2. These are substantially different than the estimates for CEAREX. The SHEBA Young's moduli are about 2 GPa smaller than those of CEAREX, with significantly more variations with depth in the ice.

We chose to calculate a new set of relative noise level curves at 500 Hz based on the estimated Young's moduli for days 290, 345, and 405, 1997. We also employed a sound speed profile that is appropriate for the location of SHEBA in the Arctic Ocean. The relative noise curves for SHEBA provide the noise expected for a fracture at a given depth in the ice based on the seismo-acoustic propagation within the ice and underlying ocean. As before, the acoustic energy from a surrounding region with a diameter of 100 km was summed to obtain the net acoustic energy at a given depth within the water column.

A comparison between the observed and model-predicted noise is presented in Fig. 3. There are some similarities between the noise levels, but in general the two are quite different. Based on our analyses, we had expected this. The results in Fig. 3 further support the contention that the variations seen in the observed higher frequency noise are not being driven by thermal fracturing.

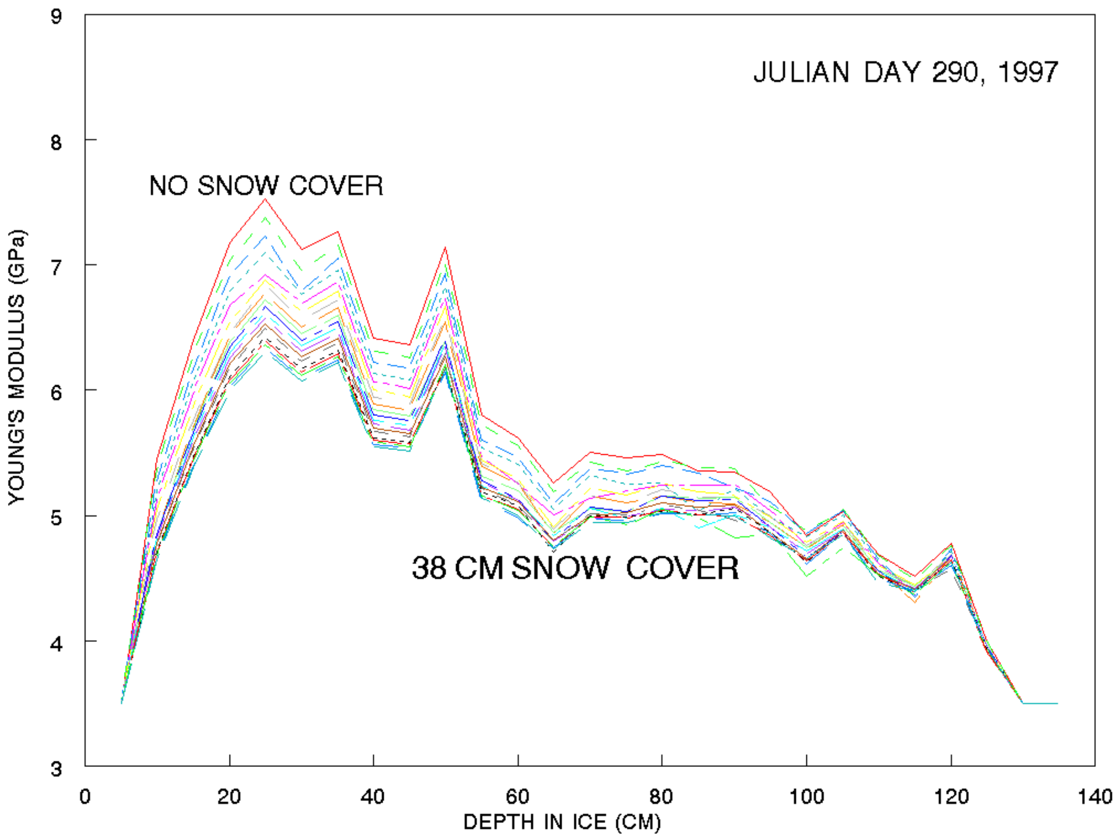

Fig. 2. Estimates of the Young's moduli within the pack ice for day 290, 1997.

IMPACT/APPLICATIONS

One of the factors pointed out in our simulations is the importance of having as much stress data as possible in the vertical. The stress gauges are of the order of 25 cm in length, and this limits the number of gauges that can be put in the vertical. However, we would be much more confident in our model results if there had been stress data in the middle third of the ice.

The hydrophone data need to be re-examined more closely for reliability. Although most of the data appears typical, there are some sections that display peculiar characteristics. Further investigation into the hardware and the processing software is merited.

TRANSITIONS

A proposal is being submitted to ONR to continue this study.

RELATED PROJECTS

SSI continued to research the possibility of measuring low-frequency, low-amplitude flexural-gravity waves to infer average ice thickness in the Arctic. During the APLIS/SCICEX ice camp in April 1999, SSI deployed two systems that measured the ice tilt in a series of experiments designed to test the robustness of these systems. Tests seemed to confirm that the systems accurately capture the characteristics of these waves, but a low signal-to-noise ratio and inadequate sampling periods prevented us from collecting reliable data. A previous winter-over deployment showed that a system such as this using batteries and solar panels could remain functioning indefinitely. SSI has high confidence that with little additional effort, an autonomous system could be developed that would accurately measure the flexural-gravity waves.

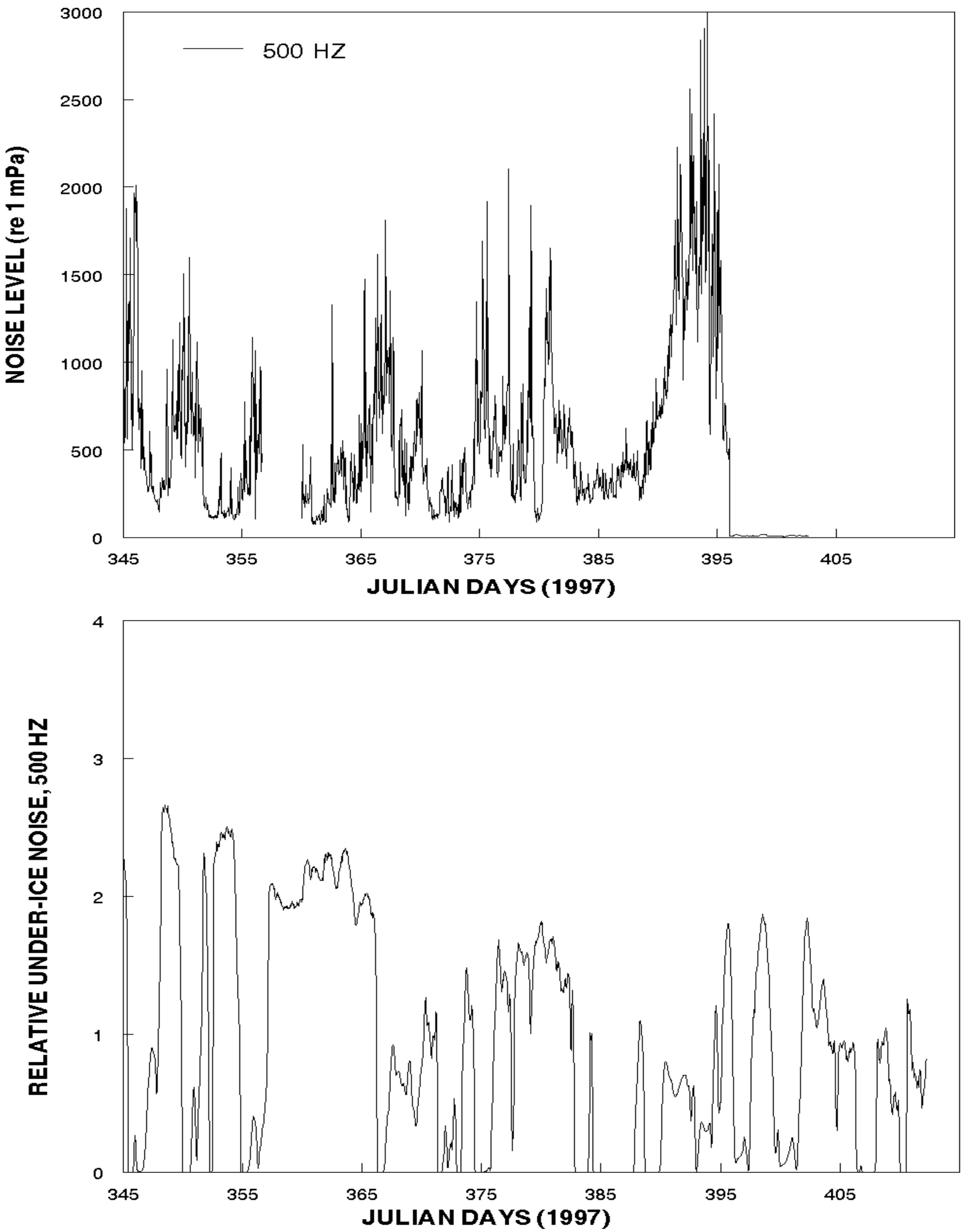

Fig. 3. Observed (top) and predicted (bottom) noise at 500 Hz.

PUBLICATIONS

Stein, P., Lewis, J.., Parinella, J. and Euerle, S., (accepted 1999): Under-ice noise resulting from thermally-induced fracturing of the Arctic pack ice: theory and a test case application, Journal of Geophysical Research.

Stein, P., Lewis, J., and Parinella, J., 1999: Under-ice noise resulting from thermally-induced fracturing of the Arctic pack ice: theory and a test case application, presentation during Acoustical Society of America meeting.